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CONTROL SYSTEMS DEVELOPMENT DIVISION

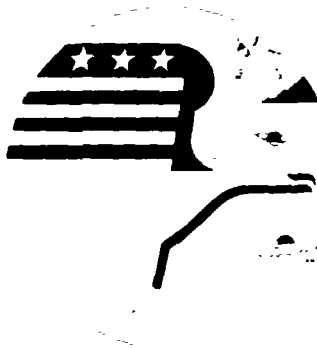
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OF THREE-PHASE INDUCTION MOTORS (NASA) 40 p
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PERFORMANCE CHARACTERISTICS
OF THREE-PHASE INDUCTION MOTORS



National Aeronautics and Space Administration
LYNDON B. JOHNSON SPACE CENTER
Houston, Texas

MAY 1977

JSC-12899

CONTROL SYSTEMS DEVELOPMENT DIVISION

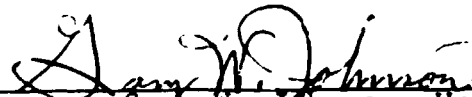
INTERNAL NOTE 77-EG-16


PERFORMANCE CHARACTERISTICS
OF THREE-PHASE INDUCTION MOTORS

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ABSTRACT

This report summarizes an investigation into the characteristics of three-phase, 400 Hz, induction motors of the general type used on aircraft and spacecraft. Results of laboratory tests conducted in the PDCL (Power Distribution and Control Laboratory) are presented and compared with results from a computer program developed by the PDCB (Power Distribution and Control Branch). Representative motors were both tested and simulated under nominal conditions as well as off-nominal conditions of temperature, frequency, voltage magnitude, and voltage balance. Good correlation was achieved between simulated and laboratory results. The primary purpose of the program was to verify the simulation accuracy of the computer program, which in turn will be used as an analytical tool to support the Shuttle Orbiter. Orbiter 102 and subsequent vehicles require approximately 250 motors of the general type described above. A good understanding of the characteristics of these motors is essential.

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1.0 INTRODUCTION

The Space Shuttle Orbiter (OV-102 and subsequent vehicles) will have a complement of approximately 275 electric motors of various types and sizes. For most applications, the three-phase induction motor has been selected because of its availability, reliability, and relatively low cost. A thorough knowledge of the characteristics and limitations of this type motor is required to make sound technical judgments on its application.

This program consisted of two separate activities: (1) A laboratory test phase where several representative motors were tested on a dynamometer to obtain torque-speed curves under various nominal and off-nominal conditions, and (2) a computer simulation which predicts the performance of these same motors under similar conditions. Of interest is the performance of the motor under unbalanced voltage and phase conditions including loss of one phase and performance at each end of the temperature, frequency, and voltage limits. The motors for the test were selected to cover the speed and horsepower range of the majority of OV-102 motors. The laboratory portion of this task was accomplished by LEC (Lockheed Electronics Co.) under Contract NAS 9-12200 and is reported in reference 1.

2.0 LABORATORY TEST PROGRAM

2.1 TEST ARTICLES

ITEM	PART NO.	MANUFACTURER	SPEED (RPM)	HORSE- POWER	NO. OF WIRES
1	42010309-11	Sawyer Ind. Inc.	10,700	0.12	4
2	FBT 3815-2	IMC Magnetics Inc.	5,250	0.50	3
3	FBT 2918-6	IMC Magnetics Inc.	7,000	0.25	3
4	FBT 2914-7	IMC Magnetics Inc.	10,500	0.25	3
5	FBT 2914-8	IMC Magnetics Inc.	7,000	0.125	3
6	FBT 2910-14	IMC Magnetics Inc.	10,500	0.125	3
7	1609	IMC Magnetics Inc.	10,500	0.015	3

2.2 TEST SET-UP

Figure 1 shows a typical set-up used throughout the test. The list of equipment is as follows:

ITEM	DESCRIPTION	MANUFACTURER	MODEL NO.
1	Wattmeter	Sensitive Research	U21398
2	Wattmeter	Grumman Aircraft Eng. Corp.	203-1
3	Wattmeter	Grumman Aircraft Eng. Corp.	203-1
4	Voltmeter	Weston	433
5	Ammeter	Weston	904
6	Ammeter	Weston	904
7	Ammeter	Weston	904
8	Current Sensor	American Aerospace Controls	1002-50-400
9	Watt Transducer	Scientific Columbus	XL34-2KSA2

ITEM	DESCRIPTION	MANUFACTURER	MODEL NO.
10	X-Y Recorder	Honeywell	500
11	Recording Oscilloscope	C.E.C.	5-124A
12	Power Supply	Invertron	1001-T
13	Dynamometer	Magtrol	HD500-8
14	Digital Indicator	Magtrol	4605-C
15	Power Supply	Magtrol	4609/4772

2.3 EQUIVALENT CIRCUIT PARAMETERS

This portion of the test program was used to measure parameters of each motor for input to the computer program. The equivalent circuit of an induction motor is shown in figure 2. The analytical model used by the computer to simulate the motor is this electrical equivalent of the motor; therefore, values of the circuit parameters are essential. Most textbooks on a.c. machinery describe the methods used to obtain these parameters from "no-load" and "blocked rotor" tests. This is described very thoroughly in reference 3. The LEC report (reference 1) includes a table listing these parameters for all the motors under test. Results from only one motor will be presented in this report and this motor will be used as an example throughout the report:

Mfg - Sawyer Industries, Model No. 42010304-11, 200 volts,
0.12 horsepower, 3-phase, 4-wire.

$R_1 = 10.02$ ohms, $R_2 = 17.54$ ohms, $X_1 = X_2 = 16.7$ ohms,
 $X_m = 196$ ohms, $R_m = 0$ (assumed).

The values for winding resistance presented in LEC report were obtained at room temperature. The resistance values presented above have been extrapolated to a 0°C reference for compatibility

with the computer program. It should be pointed out that the accuracy of the computer program can only be as good as the accuracy of these parameters. Several assumptions are used in obtaining them from "no-load" and "blocked rotor" tests. Also several different methods are recognized to calculate the values and separate out the motor losses. Good laboratory test techniques are also critical in arriving at accurate values. One of the purposes of this investigation is to compare results between the laboratory test data and the computer simulation and to use this to refine the assumptions and techniques. Such variations will be discussed as they are made later in the report.

2.4 PERFORMANCE TESTS

2.4.1 Test Method

These tests were conducted with a set-up as shown in figure 1. The objective of the test is to measure motor performance at various torque loads ranging from stall (or starting) to no load. The points of greatest interest will be the stall torque, breakdown torque, and full load (or normal running) torque. These are shown for reference in figure 3 which is a torque speed curve for the Sawyer motor under nominal conditions. Nominal conditions for this motor are assumed to be as follows: balanced input voltage of 120 volts per phase with a phase angle of 120° between phases; 95°F winding temperature, and 400 Hz input frequency. Tests were also conducted at off-nominal conditions. Curves for these various conditions are shown in figures 4 through 7.

2.4.2 Effect of Input Voltage Variation (Figure 4)

Rockwell/Space Division specification (MR 0004-002), "Electrical Design Requirements for Electrical Equipment Utilized on the Space Shuttle Vehicle," permits a voltage swing of $\pm 6.1\%$ from nominal. If a linear relationship between input voltage and starting torque is assumed and these are expressed in terms of percent change from nominal, every change in input voltage of 1% will result in a change in starting torque of approximately 2%. This would indicate torque is roughly proportional to the square of the input voltage. Whereas this is not strictly true, it is a good rule-of-thumb method to estimate motor torques for small variations in input voltage. This also applies to full load torque and breakdown torque. In the case of the Shuttle Orbiter with a potential $\pm 6.1\%$ voltage swing, we can expect a torque variation on the motors, due to voltage variation alone, of approximately 12%. A point of clarification is needed at this point regarding the output of the motor at a given load (assume full load torque shown on figure 3). An induction motor operating in its stable operating region (i.e., to the right of the knee of the curve) will automatically compensate for torque changes by changing speed (or slip). By the same token, that same motor, when subjected to a lower voltage, will automatically adjust to the load at a reduced speed provided the load torque is not greater than the breakdown torque at the lower voltage. There is a practical limit on how far one can go in operating at a reduced voltage. This becomes a problem when the torque required by the load stays fixed as speed decreases. A simplified explanation of this follows: As the motor slows down (slip increases) to meet the torque demand, motor current increases. This results in increased I^2R losses in the stator and rotor and consequently

increased heating. The end result is a decrease in efficiency and potential failure. This is not a problem if adequate design margins are provided for.

2.4.3 Effect of Frequency Variation (Figure 5)

The effect of frequency changes on motor torque is not as straightforward as voltage. Figure 5 shows that starting torque and breakdown torque decrease with increasing frequency, whereas this is not apparent at the full load torque. This can partially be explained as follows: The motor is heavily inductive at the low speeds making the impedance very nearly proportional to frequency. Torque, which is proportional to current is therefore lower at the high frequency. At the high speed end the inductive effect is not nearly as dominate and the higher inherent speed of the motor causes the curve to shift in favor of the high frequency. Specification MF 0004-007 (reference 4) specifies a tolerance of ± 7 Hz (1.75%) on frequency for the Orbiter. Input power at the upper limit of this frequency range would result in a reduction in starting torque of only 3%.

2.4.4 Effect of Phase Unbalance (Figure 6)

Balanced operation is defined as follows: Each of the three phase voltages are equal in magnitude and are shifted in phase by 120° from each other. Tests were conducted with one of the three phases shifted 10° from its nominal position making it 110° from one phase and 130° from the other. Results shown on figure 6 indicate negligible effect on torque, particularly when one considers that the phase unbalance on the Orbiter will be held to less than 2° . Two-phase operation is shown plotted on this same figure since this can be considered an extreme

condition of phase unbalance. This deserves some discussion since it could exist on Orbiter in the event of a loss of one phase or failure of a motor winding. The following set of conditions is assumed:

1. The motor is 4-wire with neutral connected. (Note: If neutral is not connected, the motor will have zero starting torque under 2-phase conditions.)

2. The lost phase is electrically disconnected from the rest of the system (if the lost phase is still connected to other loads on the failed bus, the motor will generate an EMF for those loads resulting in a different motor performance characteristic).

3. Two hypothetical types of loads are assumed for the motor. Curves for these loads are shown dotted in figure 6. Curve A represents a centrifugal blower (or fan) and curve B represents a reciprocating compressor. Both loads are selected to present a rated load on the motor which is 23 oz-inches.

The intersection of the load line with the torque-speed curve is the steady state operating point. These are labeled 1, 2, and 3 on the figure. The centrifugal blower (curve A) represents a very easy load for a motor since it requires an extremely low starting torque. With this type load, the motor would start under 2-phase conditions and would run at approximately 10,350 RPM (operating point 3). With the reciprocating type load (curve B), the motor would not start with two phases since the load torque is higher than the starting torque of the motor. The motor would also run slower with the reciprocating load (approximately 9,850 RPM). Another question one might ask concerning the motor performance under 2-phase conditions is

whether or not the motor would fail. One way to approach this question is to take a look at the amount of power loss dissipated by the motor under the various conditions. The motor, operating under balanced 3-phase conditions, driving either of these loads dissipates approximately 50 watts. The same motor, operating under 2-phase conditions, dissipates from 100 to 130 watts depending on the type load. Obviously this motor will run hot under these conditions and possibly fail. Therefore, motors which are required to operate under 2-phase conditions, such as on Orbiter, must be appropriately derated.

2.4.5 Effect of Temperature Variation (Figure 7)

The effect of temperature on motor torque is shown in figure 7. Curves for three temperature values are shown. Unfortunately, the limited temperature range of the laboratory data does not tell the entire story of temperature effect on starting torque. Over the temperature range shown on these curves, the starting torque increases with decreasing temperature. This does not hold true as the temperature is decreased to zero degrees F. and below. This will be discussed later and computer predicted results will show the temperature effect down to -200°F.

2.4.6 Effect of Two-Phase Operation on Bus Voltage (Figures 8 & 9)

The above discussion on the effect of phase unbalance assumed that the deenergized phase was electrically disconnected from its respective power bus. It was pointed out that if this deenergized phase were still connected to the bus and if other loads to the bus were also connected, the back EMF of the motor winding would be impressed on those loads. These loads in turn

would draw current from the motor and affect motor performance. In effect the motor would be operating as a two-phase motor driving a mechanical load and also as a single-phase transformer powering an electrical load. This poses some interesting questions regarding the performance of the power distribution system as well as the motor itself. One test was conducted to show these effects. The test set-up is shown schematically in figure 8. As would be expected, a voltage is present on the deenergized bus due to magnetic coupling between the motor windings. This voltage is shown in figure 9 as a function of bus load in volt-amps (VA). The middle curve is most realistic since the motor has a mechanical load and the neutral is connected. The mechanical load represents less than 50% of its three-phase rating; however, this is probably a realistic situation for Orbiter motors. Under this condition then, we see approximately 91 volts on an open circuited bus and it falls rapidly to approximately 45 volts if the bus is loaded with a 240 VA load (60 ohms).

The top curve shows motor dissipation as a function of bus load. The dotted line shows the approximate dissipation of this motor under rated conditions. Anything above this will heat the motor above its rating. Notice that with no mechanical load on the motor at all, a 210 VA load will cause the motor to operate above its rated level. With a 10 oz-inch load on the motor, it will operate satisfactorily with two phases provided the bus load is less than 70 VA.

This data should not be considered in absolute terms since it is valid for only one motor and does not take into account operating environments, special mounting, design margins of safety, reactive loads, etc. It is valid only to show relative

effects on bus voltage and motor performance with varying bus loads. Additional testing is needed in this area to look at different size motors and different bus loading.

3.0 COMPUTER SIMULATION

3.1 BACKGROUND

Shuttle Orbiter 102 and subsequent vehicles require approximately 250 three-phase, 400 Hz induction motors. These motors represent a significant load on the a.c. inverters. An understanding of the performance characteristics as well as the effect on the a.c. system of this type motor is essential. For this reason, a limited computer model was developed in the summer of 1975. Dr. N. A. Demerdash of VPI (Virginia Polytechnic Institute) developed the model under the NASA/ASEE Fellowship Program. Basically it computes performance of the motor in terms of torque, horsepower, efficiency, etc., using Thevenin's equivalent circuit methods and symmetrical component transformation techniques. This model is described in detail in reference 2.

3.2 USE

3.2.1 Advantages

The computer model has three basic advantages. First, it can be used to gain information on motor characteristics when the motor itself is not available for test, provided equivalent circuit parameters of the motor can be obtained. These parameters can usually be obtained from the motor manufacturer. Second, a laboratory program to test a motor under several operating conditions is time consuming and requires a large

variety of test equipment. The computer can simulate these various conditions and obtain results in a fraction of the time. Third, the computer can easily apply destructive excitation and/or operating conditions with no fear of destroying expensive components. Worse case combinations which are difficult to realize in the laboratory can also be examined.

3.2.2 Limitations

The computer model has several limitations on accuracy and operating modes. Some of the more significant of these are discussed below:

1. The equivalent circuit is only an approximation of the actual.
2. The equivalent circuit parameters are obtained at only two points on the torque/speed curve (i.e., no load and stall).
3. Judgment factors are needed to determine whether or not skin effect in stator slots must be considered.
4. The program does not take into account nonsinusoidal input voltages.
5. Rule-of-thumb approximations are made in determining and separating out the various losses for input to the computer. These include core losses, copper losses, friction and windage losses, and stray load losses.

Even with the above limitations, good correlation between computer and laboratory results can be achieved. As was stated earlier, one of the purposes of this program was to identify the discrepancies and to use the information to refine both the computer model and laboratory test techniques. This is an area

where future work is anticipated. In some cases where absolute values are required, it may be necessary to conduct laboratory tests. In other cases where a general trend is of interest, the computer model should suffice.

3.3 RESULTS

3.3.1 Original Parameters

Motor performance characteristics were obtained for the same operating conditions previously described for the laboratory test to show the degree of correlation between laboratory and computer results. Curves are shown in figures 10 through 13. In comparing these curves with the laboratory results, it is apparent that the computer consistently shows a higher stall torque and a lower full load torque than actual. The discrepancies are significant enough that an explanation and, if possible, some refinement in the computer program or test technique is needed.

3.3.2 Improved Parameters

The laboratory data consistently shows a drooping torque characteristic as the stall point is approached. This is due to heating of the rotor and stator which is significant at low speeds. A variation in test methods could correct this problem. However, for the purpose of this report, the drooping characteristic is neglected. Future laboratory test procedures will be revised.

Textbooks on the subject of test methods to obtain equivalent circuit parameters differ in their approach to obtaining these parameters. In view of the discrepancy between computer and

laboratory results, it was decided to repeat this test using a different approach. Short circuit tests were conducted using a reduced frequency as well as reduced voltage. This more nearly simulates the actual conditions in the rotor during operation. Reactance parameters, using the revised test, were approximately 10% higher than before. Rotor resistance showed a decrease of approximately 20%. A second set of performance characteristics were obtained using the revised parameters. These results are shown in figures 14 through 17. A comparison between these curves and the laboratory data shows good correlation especially at starting and rated loads, which are the points of interest.

As an example, a comparison of the data at nominal conditions (400 Hz, 120 volts balanced, 95°F) is as follows:

Operating Parameter	Lab. Data	Computer Data	Percent Variation
Starting Torque (oz.in.)	35.0	33.6	4.0%
Full Load Speed @ 23 oz-in (RPM)	10,800	10,600	1.9%

Also for comparison purposes, figure 18 shows curves at nominal conditions obtained by the three different methods—laboratory, computer data with original parameters, and computer data with revised parameters.

5.3.3 Extreme Operating Conditions

The degree of correlation achieved using the revised parameters permits a good confidence level in the computer results. With this then, we can look at extreme and possibly destructive conditions and predict motor performance. Since the number of

extreme conditions is unlimited and for the most part of no interest insofar as Orbiter is concerned, only one such condition will be examined. Temperature seems to be the most logical since some of the Orbiter motors will experience a wide range of operating temperatures. Figure 17 shows torque speed curves for several temperatures ranging from -200°F to 250°F. Of particular interest is the changing shape of the curve as temperature is decreased. The low temperature curve has a shape very similar to a NEMA Design "A" which is characterized by normal starting torque, low slip, and high efficiency. At high temperatures the curve is similar to a NEMA Design "D" which is characterized by high starting torque, high slip, and low operating efficiency. This type characteristic is usually achieved by using higher resistant materials in the rotor. Figure 19 shows how starting and breakdown torques vary with temperature. This curve should be of interest to an applications engineer who has to select a motor for use where a large variation in operating temperature is anticipated.

4.0 CONCLUSIONS

The performance characteristics of most interest to an applications engineer using induction motors are speed, torque, and the input electrical parameters and how these vary with operating conditions. This report described the effect of several off-nominal operating conditions such as could be encountered on the Shuttle Orbiter. The data shows that frequency and phase unbalance have a very minimal effect on motor performance. For example, at the upper limit of the frequency tolerance, the starting torque is only 3% below nominal. The effect of the maximum phase unbalance is even smaller. Voltage and temperature variations have a significant effect on motor performance however, particularly on starting torque. For

example, a voltage variation of $\pm 6\%$, which could be encountered on Orbiter, affects starting torque approximately $\pm 12\%$. Temperature variations can affect starting torque by as much as 50%.

The data acquired during the laboratory portion of this program was also useful in verifying the accuracy of the computer program. As a result, some refinements in the methods used to acquire input data for the computer were developed. The computer-predicted results, for nominal operating conditions, were found to be within $\pm 4\%$ of actual test results. This is considered satisfactory where trends rather than absolute values are required.

5.0 REFERENCES

1. Lockheed Electronics Co., Motor Characteristics Test Program, Phase 1 Induction Motors, LEC-9014, June 1976.
2. Nabeel A. O. Demerdash, Behaviour of Space Shuttle Electrical Power System Load (Motors) Under Severe Environment in Space with Applications to Load Steady-State and Dynamic Characteristics, JSC-09841, August 5, 1975.
3. Alger, P. L., Induction Machines, Gordon and Breach Science Publishers, New York, 1970.
4. Space Division, Rockwell International, Electrical Design Requirements for Electrical Equipment Utilized on the Space Shuttle Vehicle, MF-0004-002, June 1974.

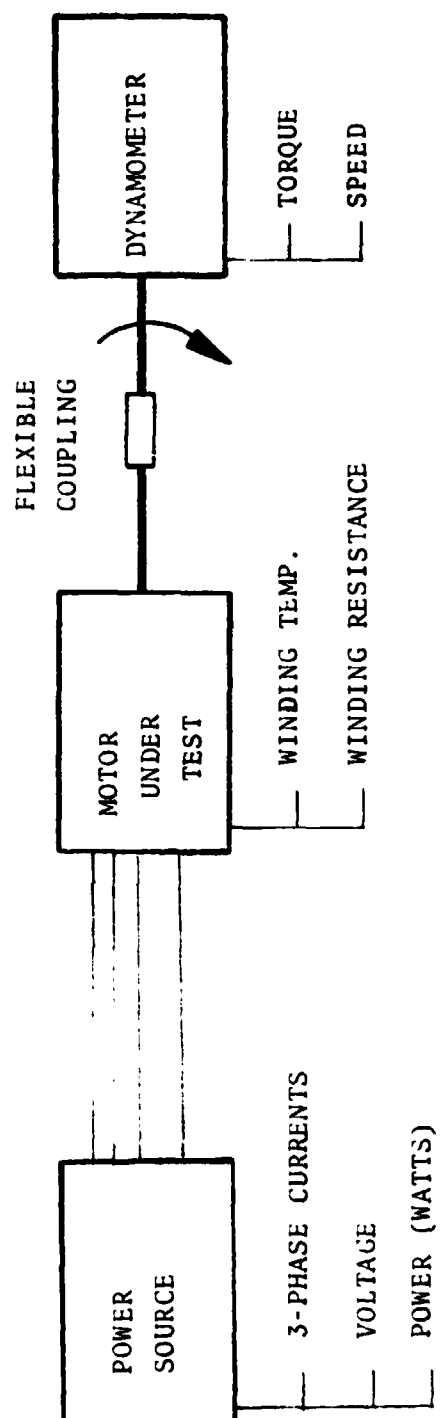


FIGURE 1. TEST SET-UP

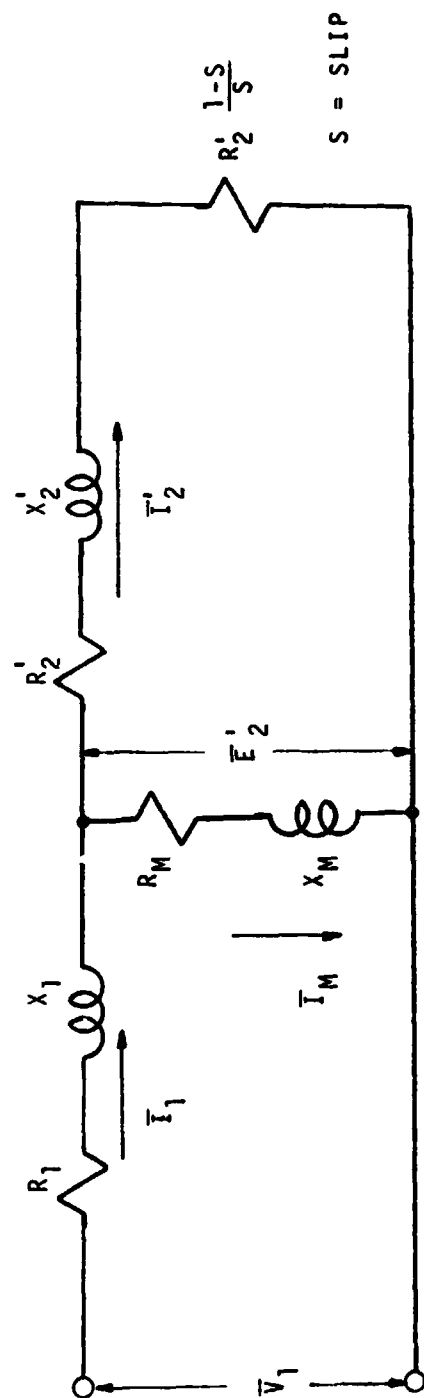
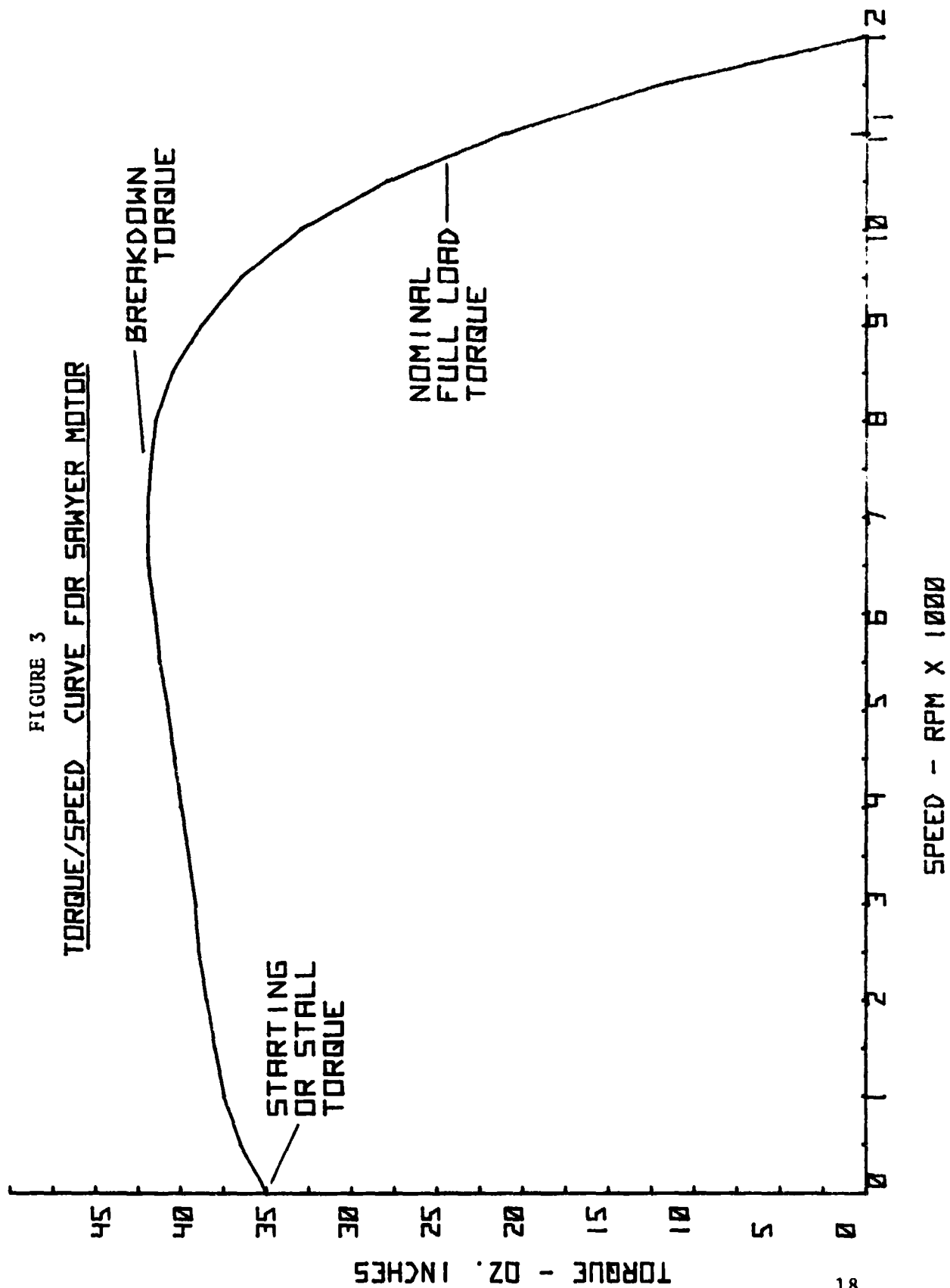


FIGURE 2. EQUIVALENT CIRCUIT OF 3-PHASE IND. MOTOR (PER PHASE)

FIGURE 3

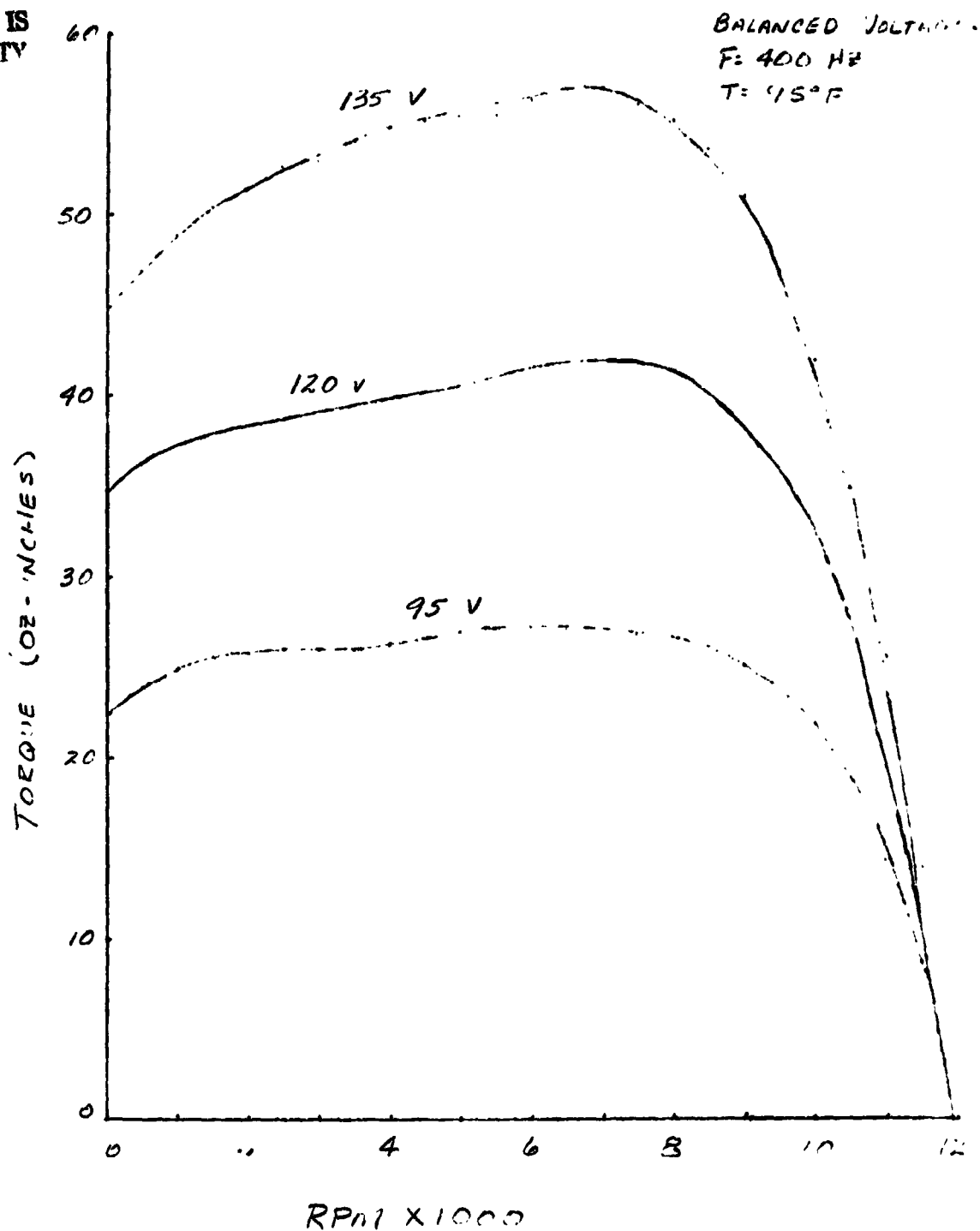
TORQUE/SPEED CURVE FOR SAWYER MOTOR



BY MMU DATE 1-28-77 SUBJECT SAWYER MOTOR SHEET NO. OF
 CHKD. BY DATE P/N 42010309-11; 30; 400Hz JOB NO.
 LAB. DATA 0.12 HP; 10,700 RPM

FIGURE 4
EFFECT OF INPUT VOLTAGE VARIATION

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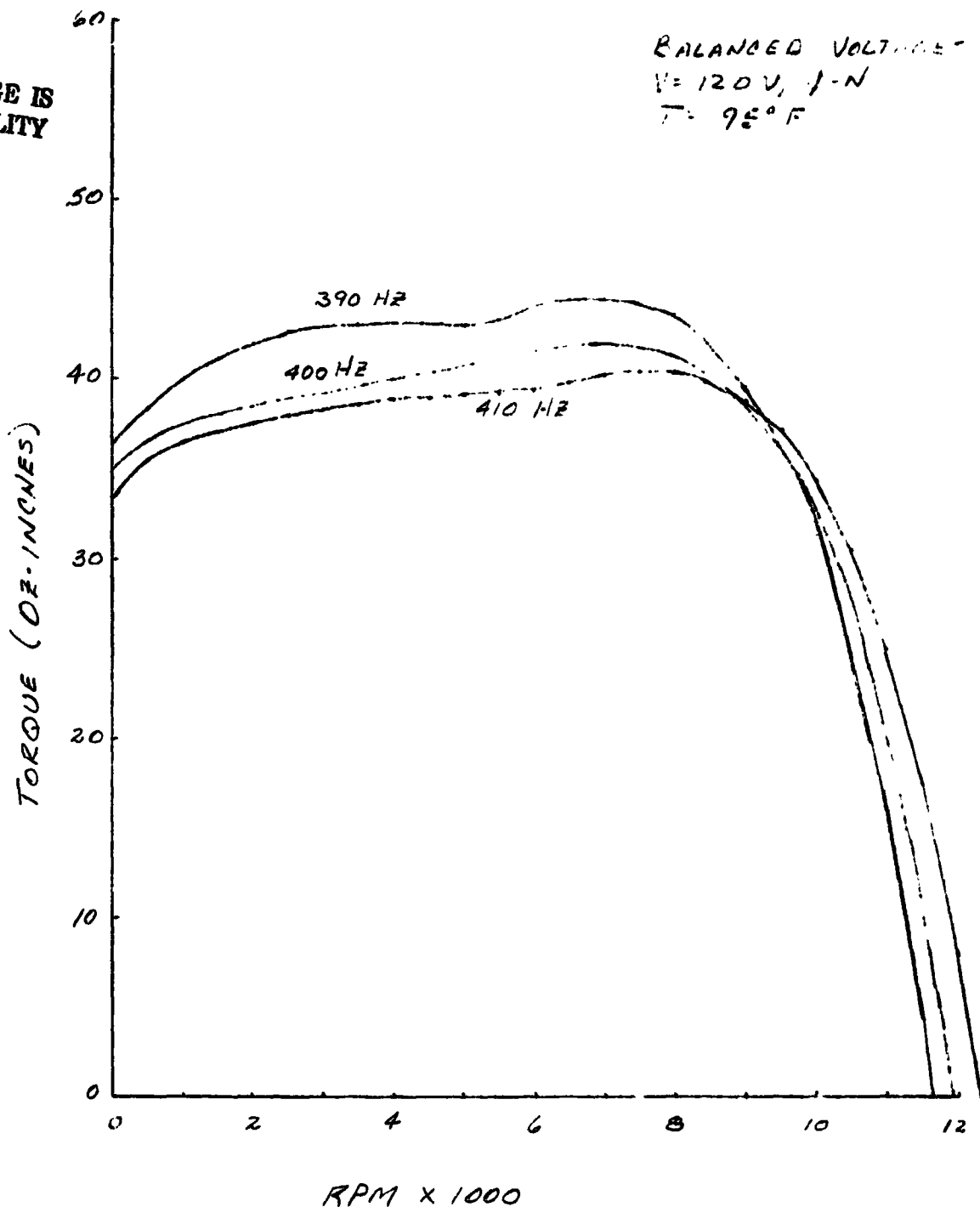


BY MMW DATE 1-28-77
CHKD. BY _____ DATE _____
LAB. DATA _____

SUBJECT SAWIER MOTOR
P/N 42010301-11; 30; 400 Hz
0.12 HP; 19,700 RPM

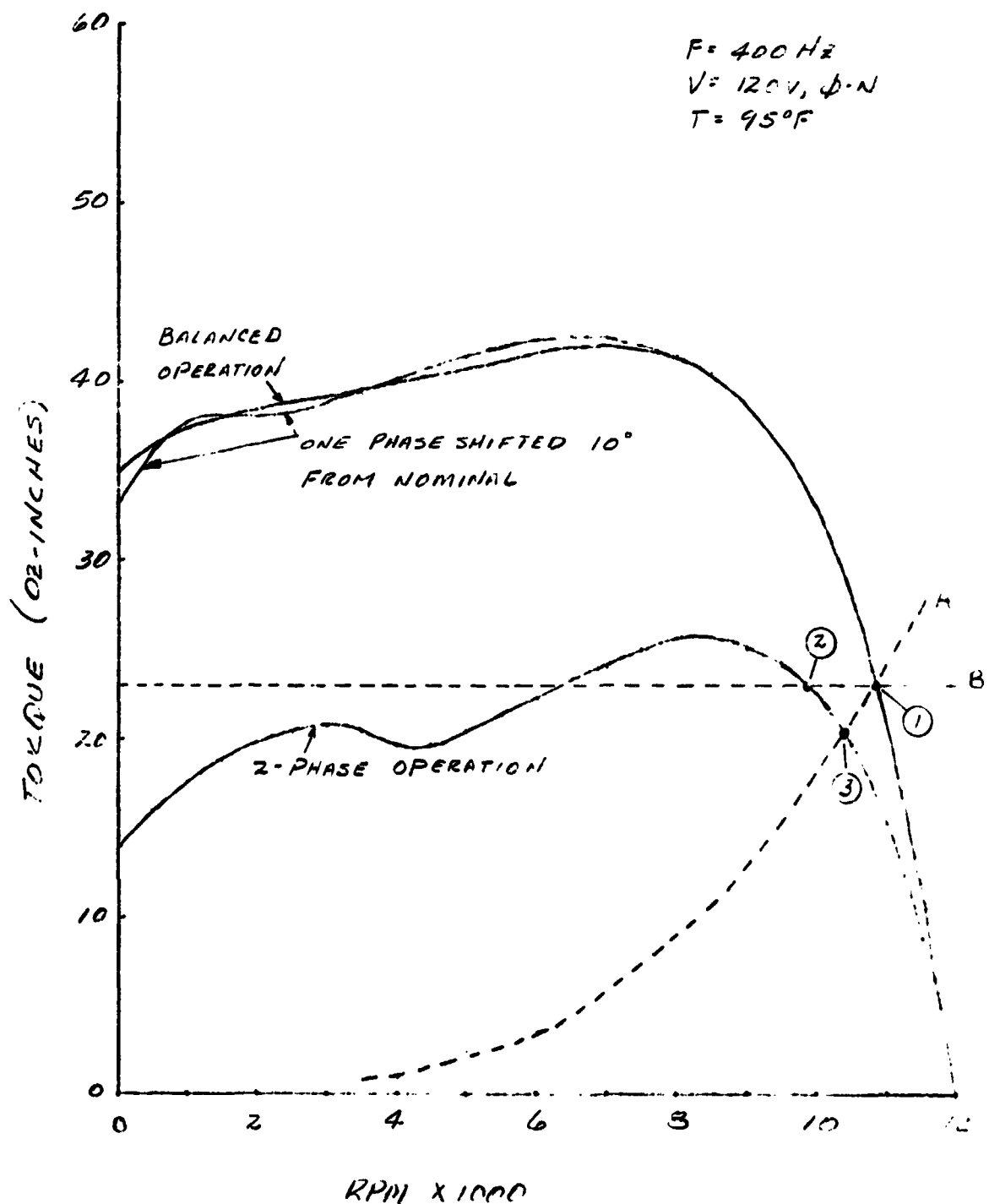
SHEET NO. _____ OF _____
JOB NO. _____

FIGURE 5
EFFECT OF FREQUENCY VARIATION



BY <u>THW</u>	DATE <u>1-28-77</u>	SUBJECT <u>SHAW-WALK MOTOR</u>	SHEET NO. _____ OF _____
CHKD. BY _____	DATE _____	<u>P/N 42010309-11130; 400 Hz</u>	JOB NO. _____
LAB. DATA _____		<u>0.12 HP; 10,700 RPM</u>	

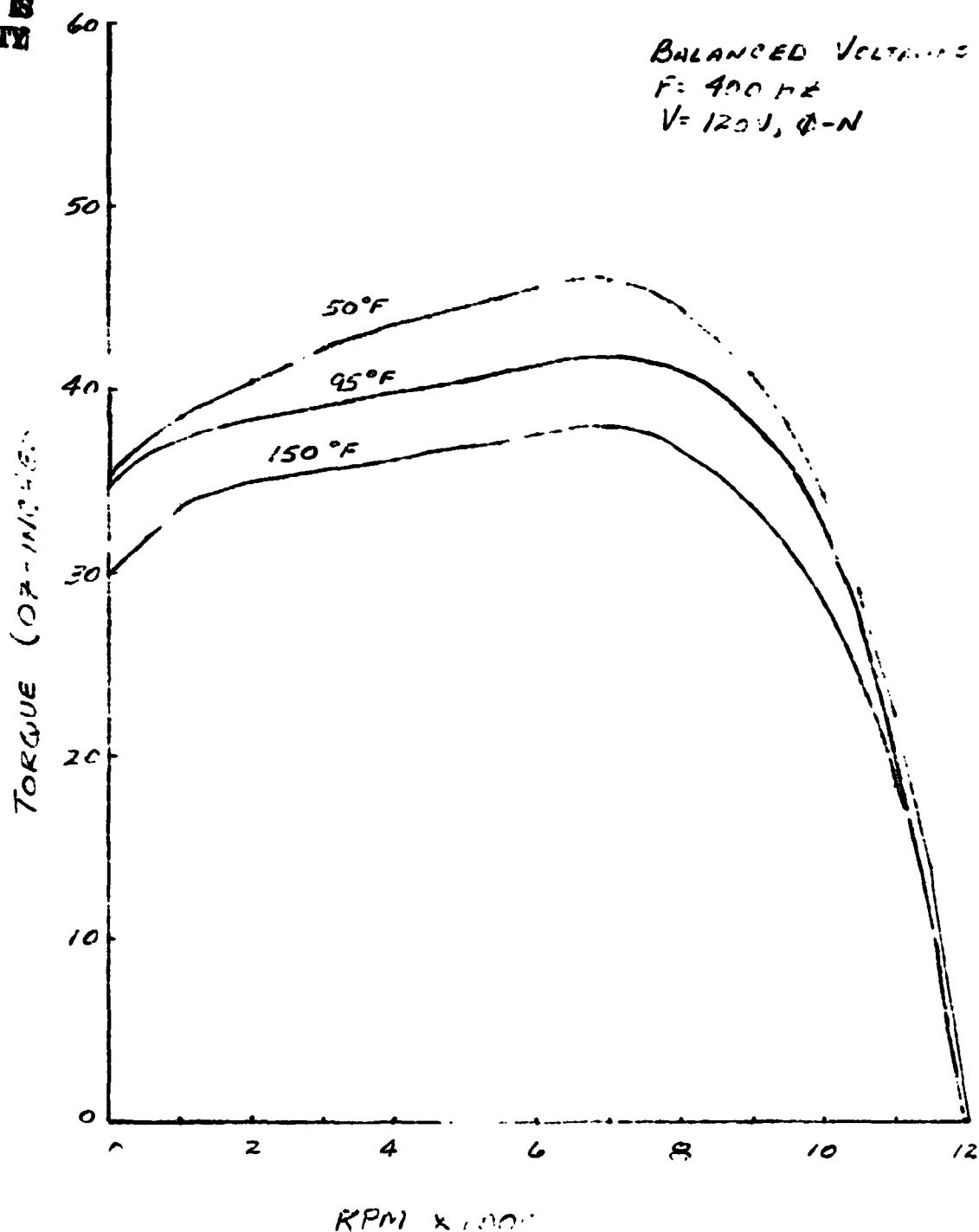
FIGURE 6
EFFECT OF PHASE UNBALANCE



BY T. H. W. DATE 1-11-77 SUBJECT SAWYER MOTOR SHEET NO. OF
 CHKD. BY DATE P/N 42010309-11; 3Φ; 400 Hz JOB NO.
 LAB. DATA 0.12 HP; 10,700 RPM

FIGURE 7
EFFECT OF TEMPERATURE VARIATION

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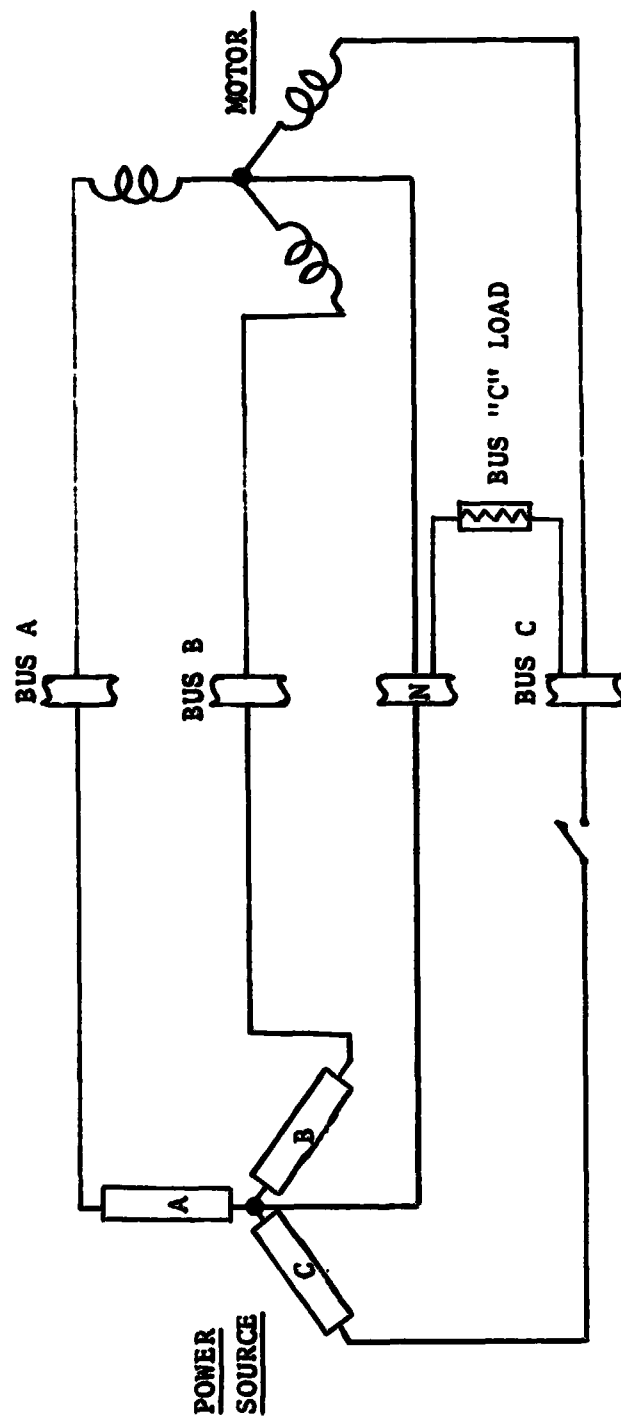


FIGURE 8. TWO PHASE OPERATION TEST SET-UP

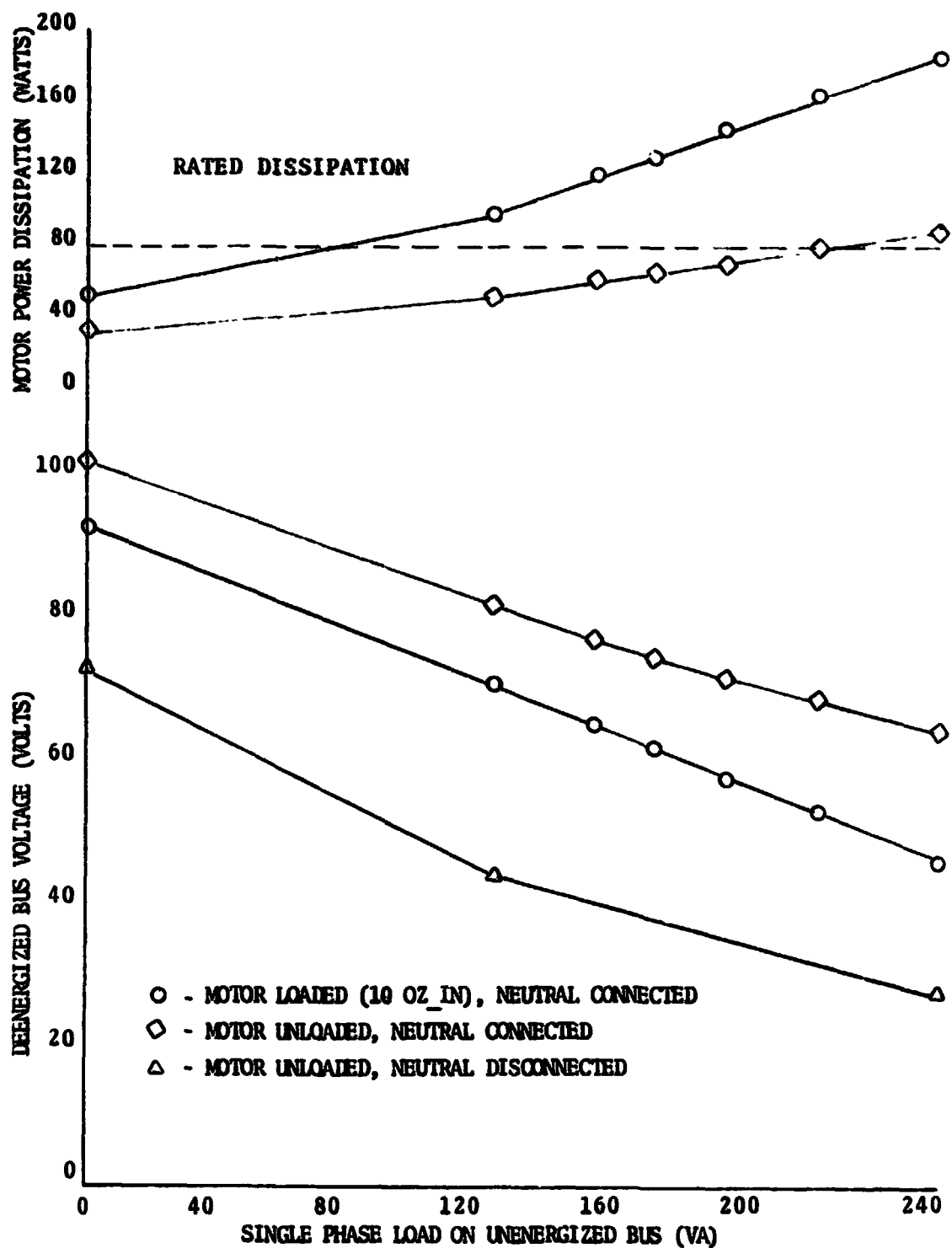
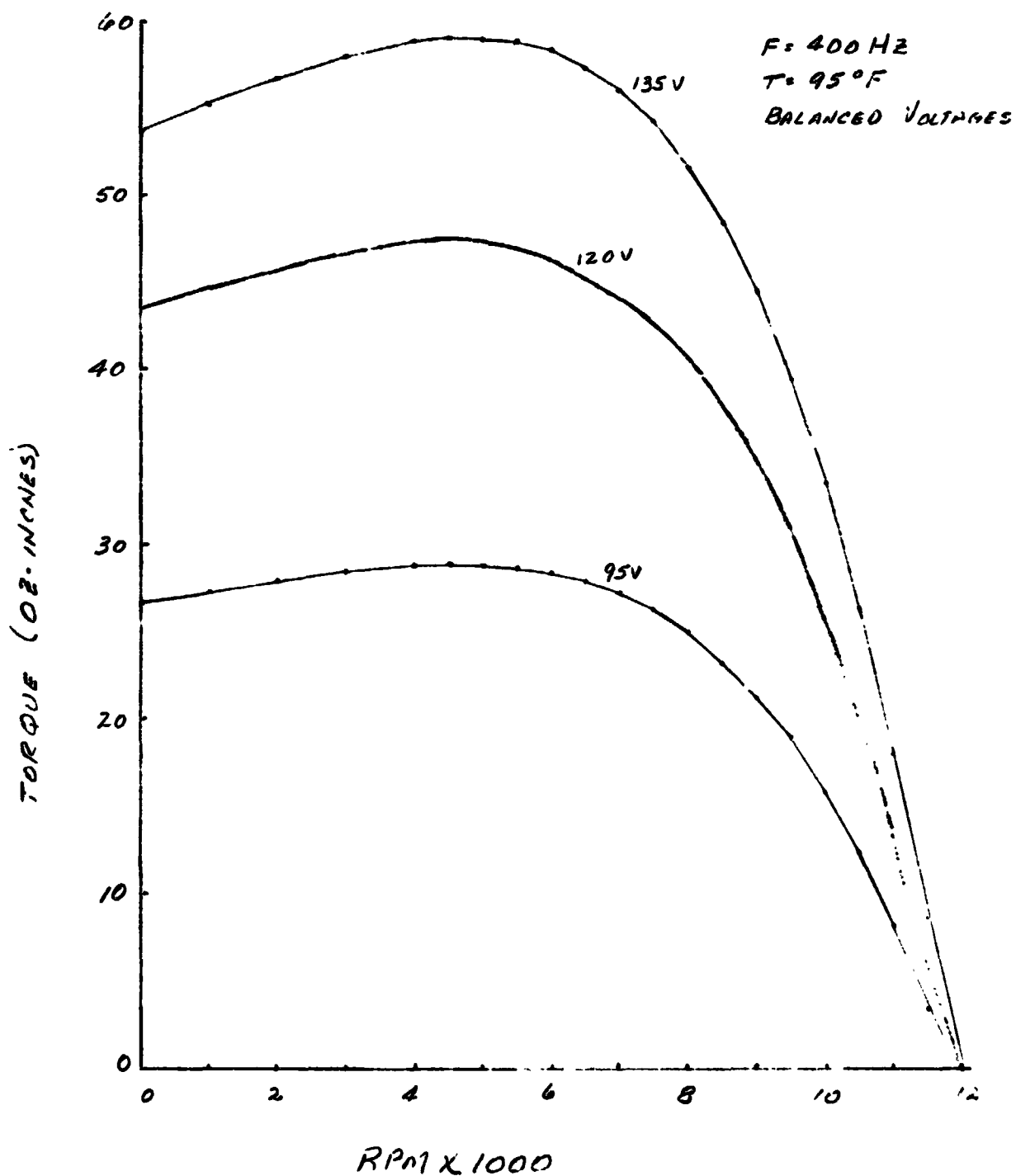


FIGURE 9. EFFECT OF 2-PHASE OPERATION ON BUS VOLTAGE

BY 2.22W DATE 2-8-77 SUBJECT SAWYER MOTOR SHEET NO. _____ OF _____
CHKD. BY _____ DATE _____ JOB NO. _____
COMPUTER DATA #1

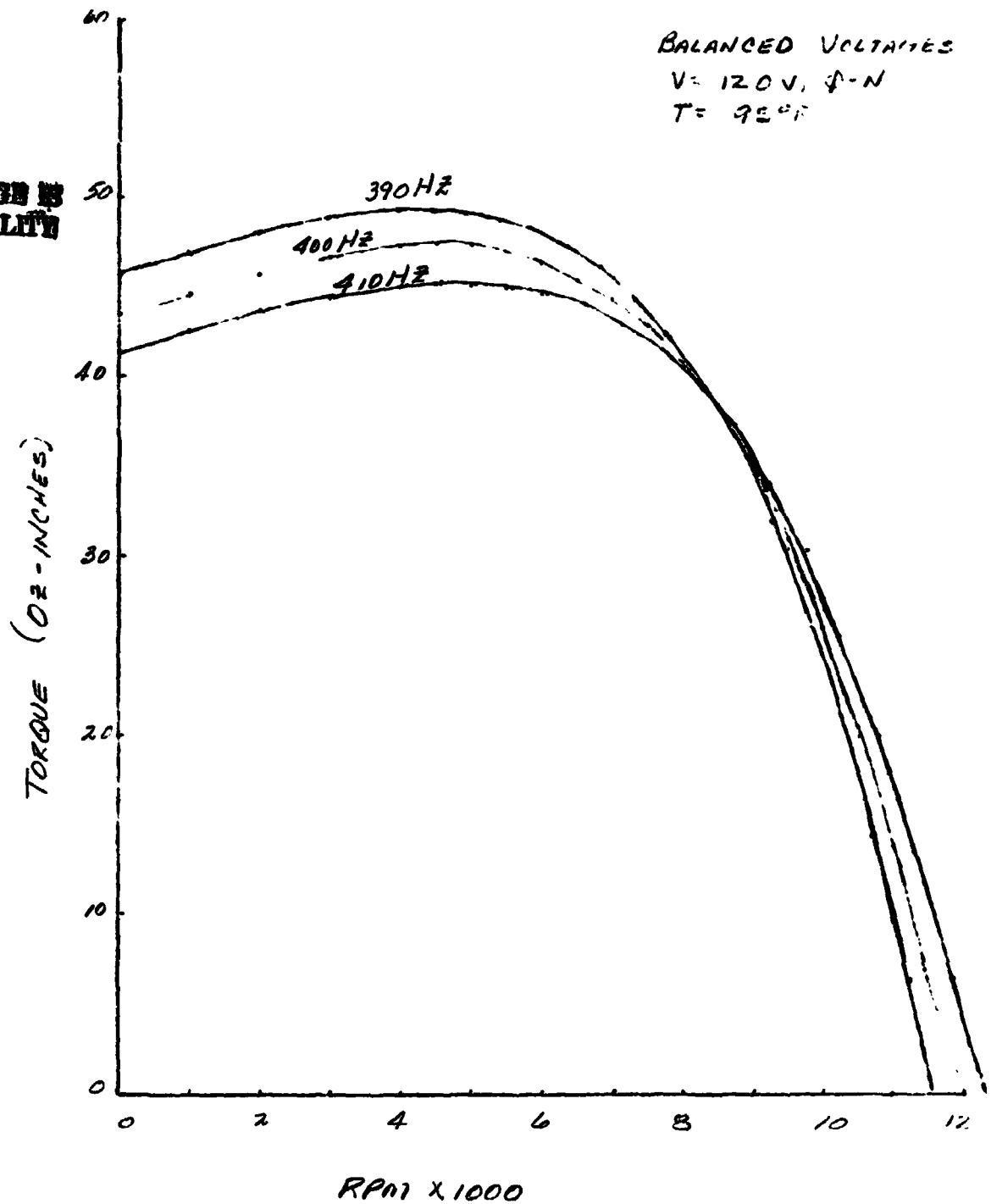
FIGURE 10
EFFECT OF INPUT VOLTAGE VARIATION



BY <u>211941</u>	DATE <u>4-72</u>	SUBJECT <u>SANXER MOTOR</u>	SHEET NO. _____ OF _____
CHKD. BY _____	DATE _____	<u>PN 42-10209-11; 30; 400HZ</u>	JOB NO. _____
COMPUTER DATA #1		<u>0.12 HP; 10,700 RPM</u>	

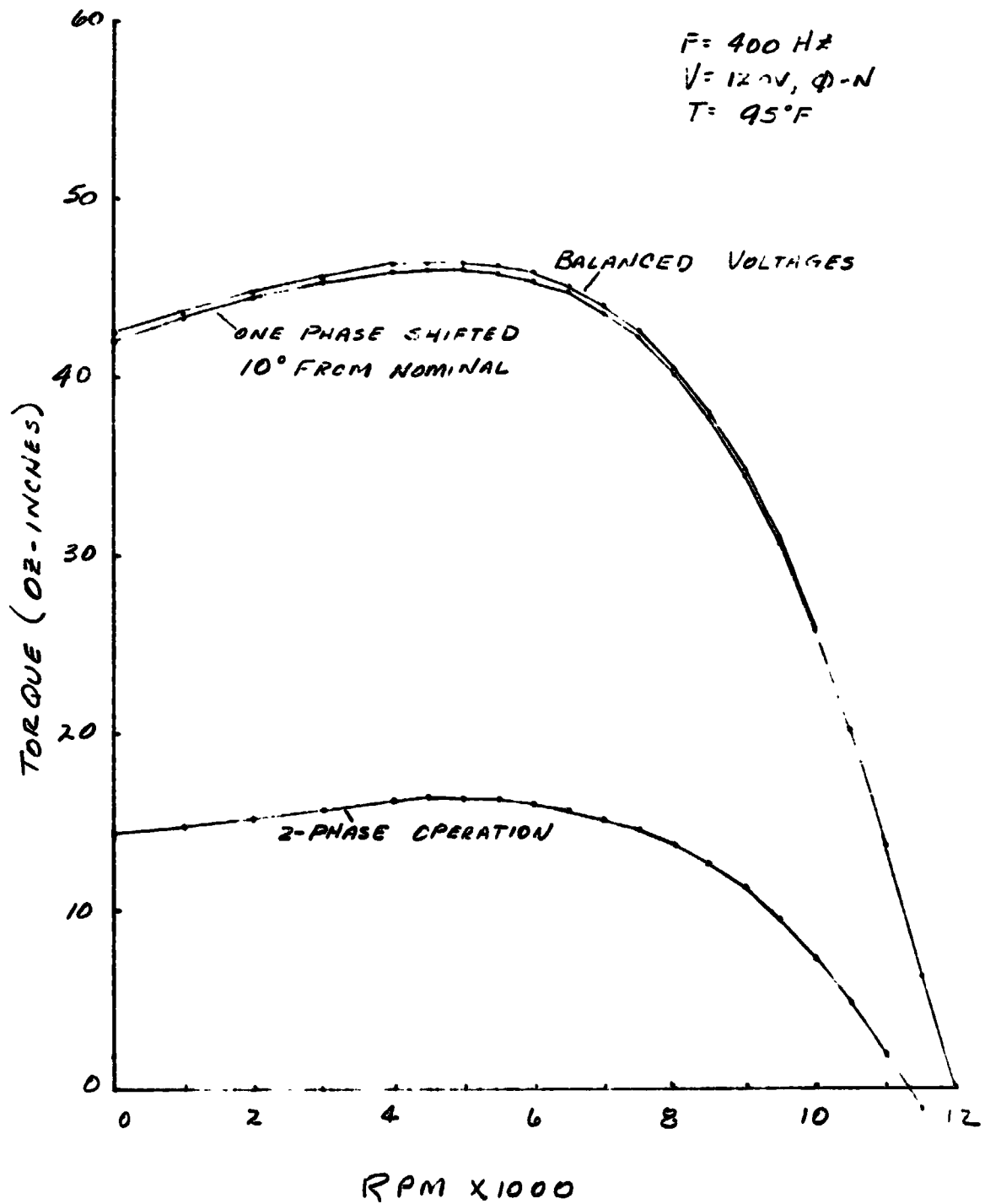
FIGURE 11
EFFECT OF FREQUENCY IN MOTION

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OF POOR QUALITY



BY 714N DATE 2-8-77 SUBJECT SAWYER MOTOR SHEET NO. _____ OF _____
 CHKD. BY _____ DATE _____ P/N 42010309-11; 3 ϕ ; 400 Hz JOB NO. _____
 COMPUTER DATA #1 012 HP; 19200 RPM

FIGURE 12
EFFECT OF PHASE UNBALANCE



BY THP DATE 2-8-77
CHKD. BY _____ DATE _____
(COMPUTER DATA #1)

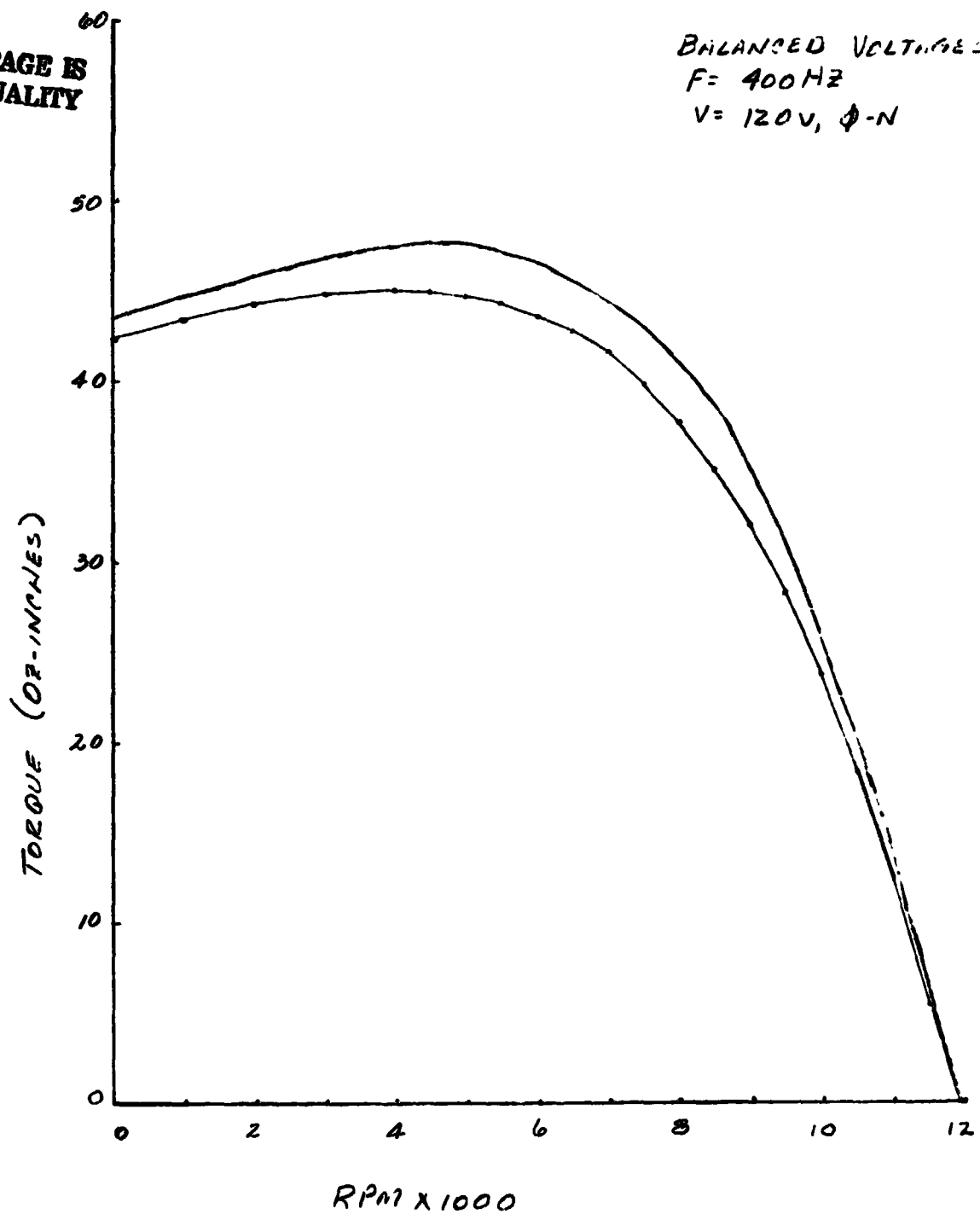
SUBJECT SAWYER MOTOR
P/N 4240308-11; 3 ϕ ; 400 Hz

SHEET NO. _____ OF _____
JOB NO. _____

FIGURE 13
EFFECT OF TEMPERATURE VARIATION

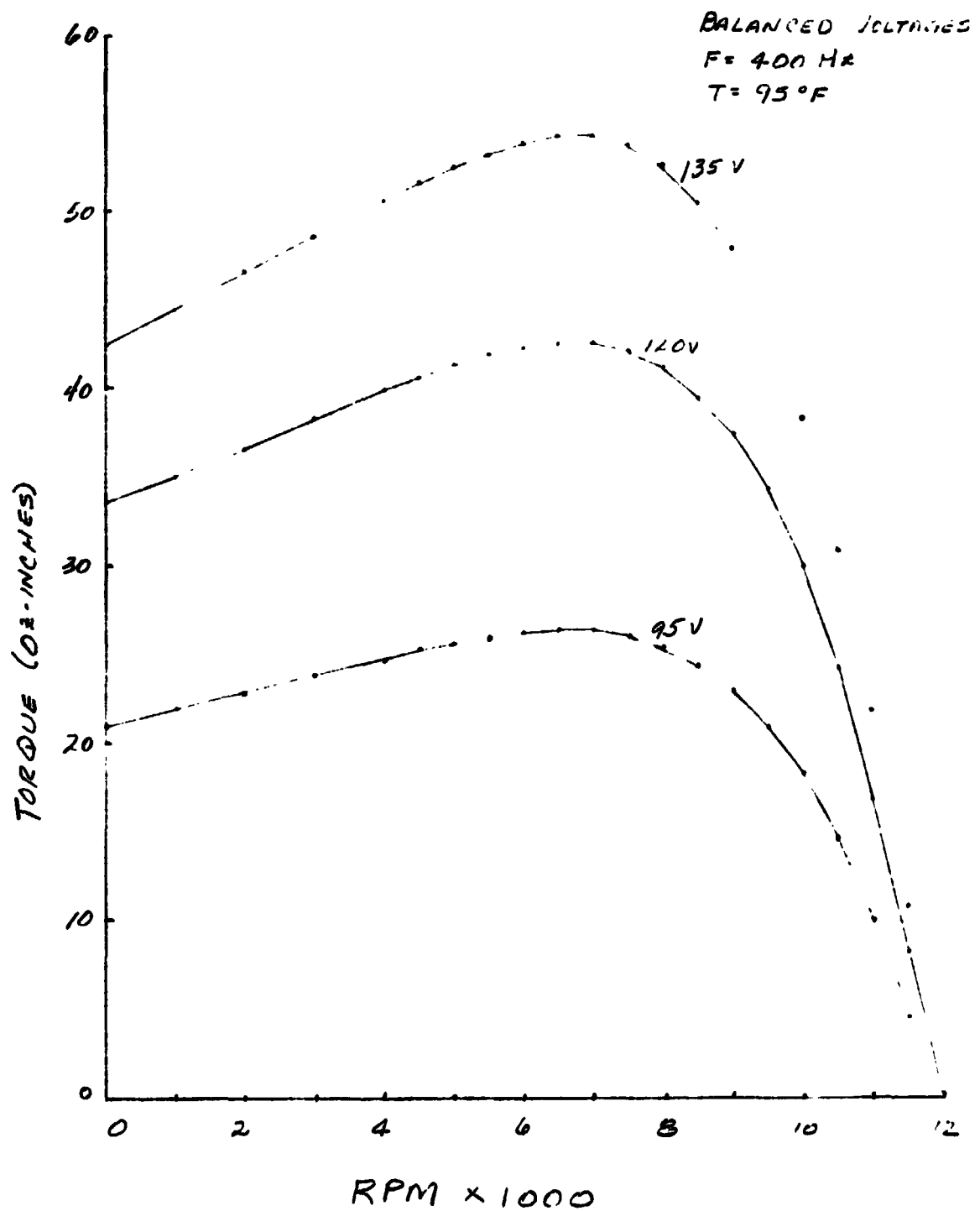
ORIGINAL PAGE IS
OF POOR QUALITY

BALANCED VOLTAGES
 $F = 400 \text{ Hz}$
 $V = 120 \text{ V}, \phi - N$



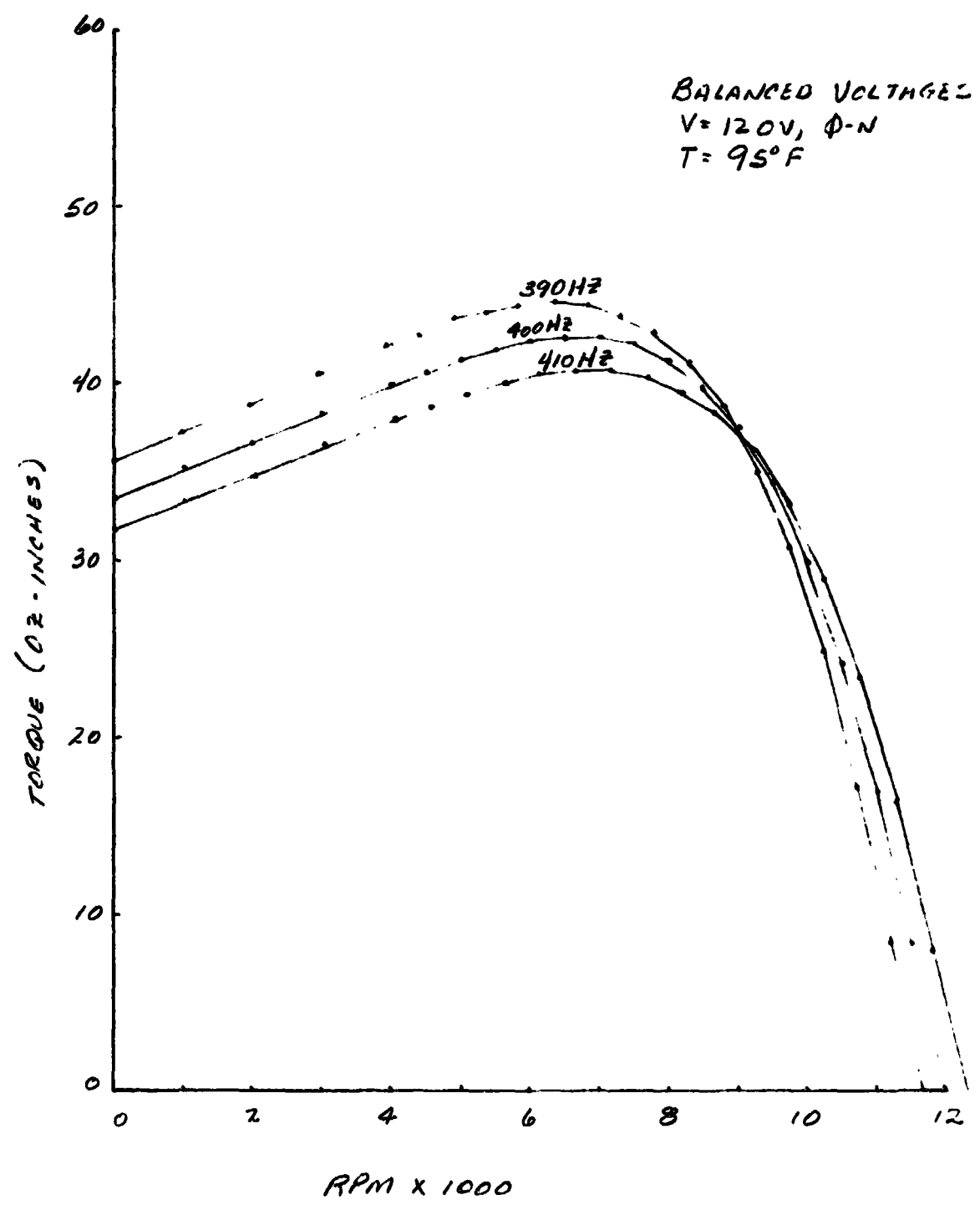
BY <u>D. 18N</u>	DATE <u>2-12-77</u>	SUBJECT <u>SAWYER MOTOR</u>	SHEET NO. _____ OF _____
CHKD. BY _____	DATE _____	<u>PN 42010309-11; 3ϕ; 400 Hz</u>	JOB NO. _____
<u>SCATTER DATA #2</u>		<u>0.12 HP; 19700 RPM</u>	

FIGURE 14
EFFECT OF VOLTAGE VARIATION



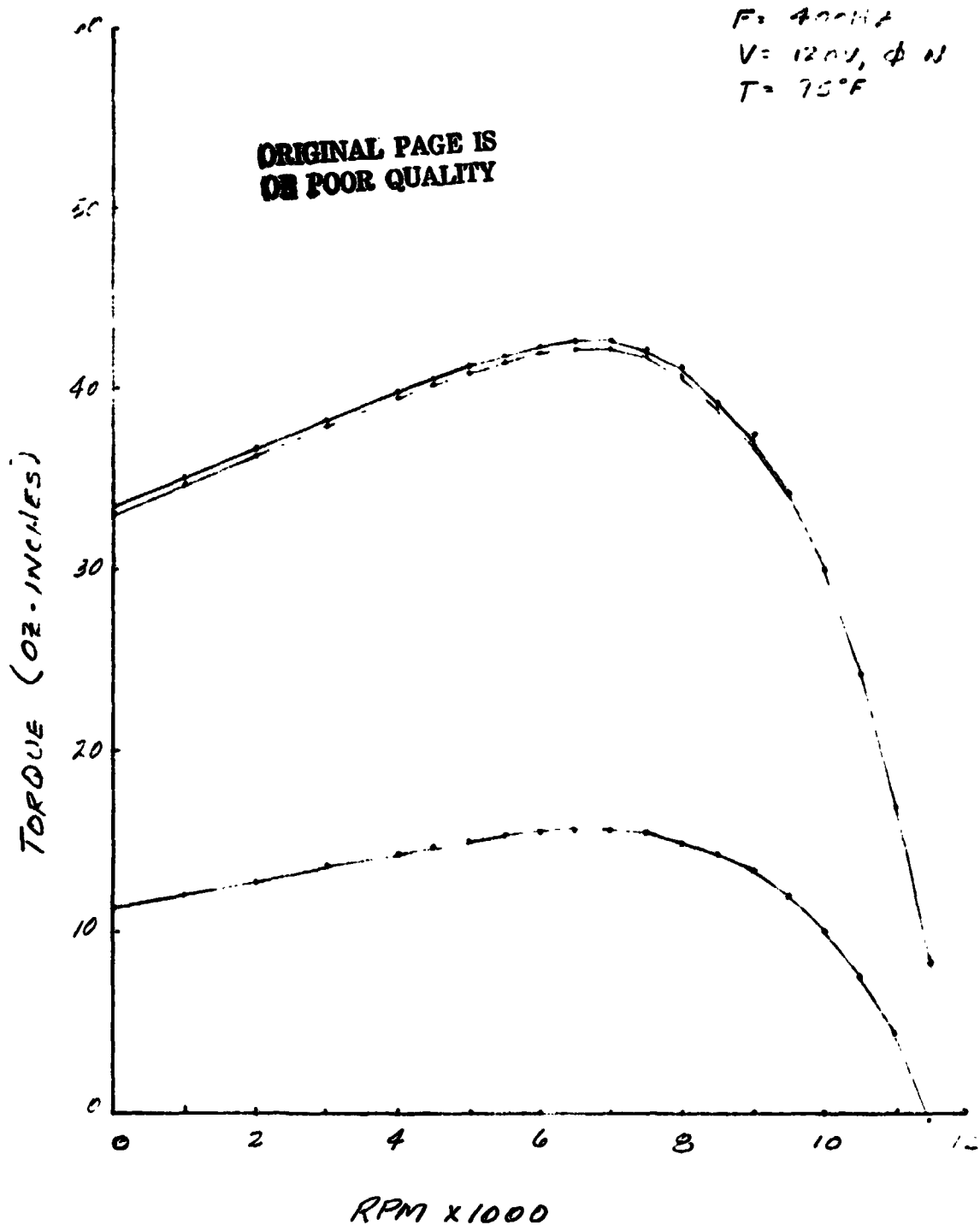
BY <u>WJH</u>	DATE <u>2/12/77</u>	SUBJECT <u>SAWYER MOTOR</u>	SHEET NO. _____ OF _____
CHKD. BY _____	DATE _____	P/N <u>42010309-11; 30; 400 HZ</u>	JOB NO. _____
COMPUTER DATA # <u>2</u>		<u>0.12 HP; 10,700 RPM</u>	

FIGURE 15
EFFECT OF FREQUENCY VARIATION



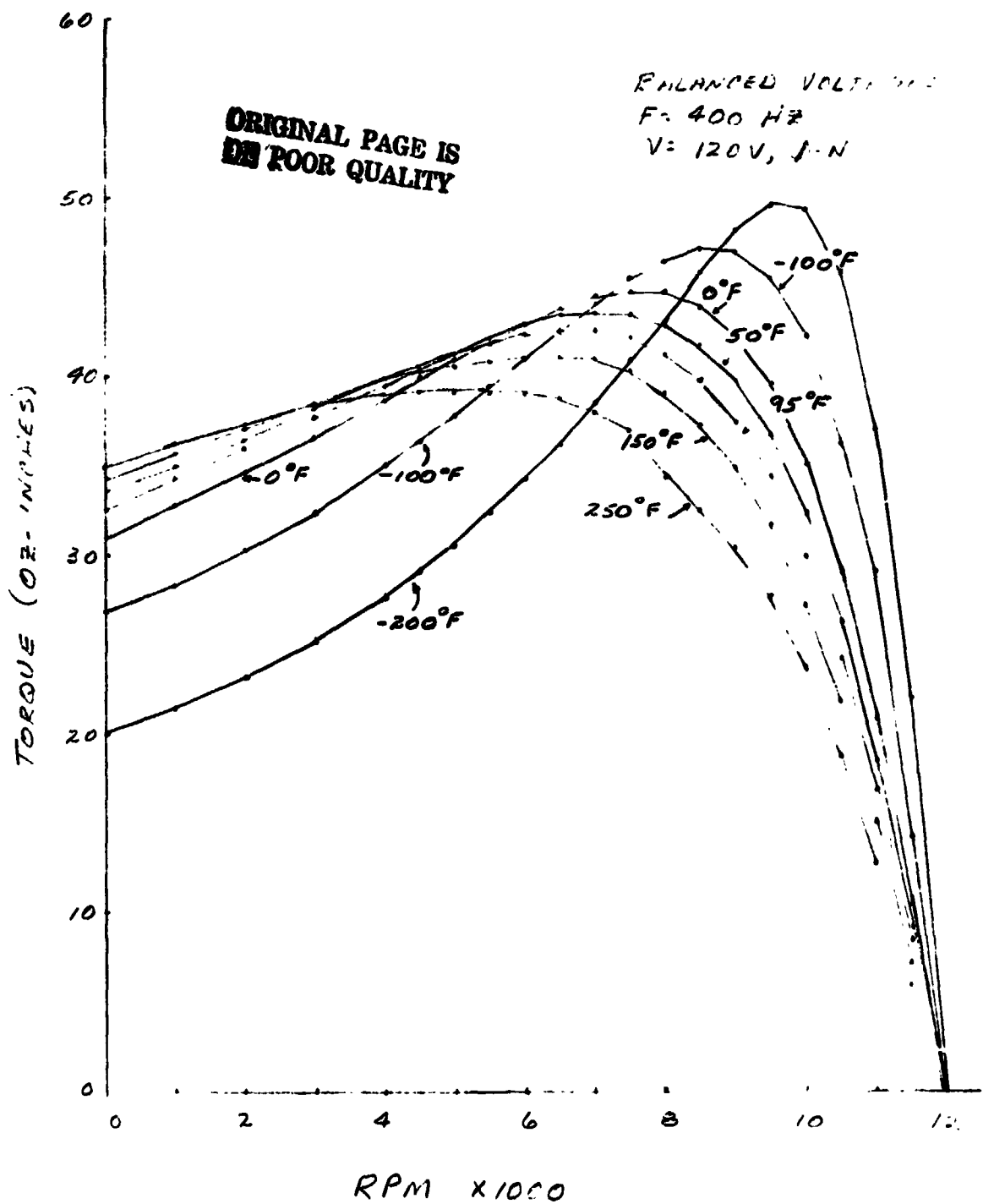
BY <u>711411</u>	DATE <u>2-2-77</u>	SUBJECT <u>WILLYER MOTOR</u>	SHEET NO. _____ OF _____
CHKD. BY _____	DATE _____	<u>PH 470,000, 32; 400 Hz</u>	JOB NO. _____
<u>COMPUTER DATA #2</u>		<u>0.12 HP; 10,700 RPM</u>	_____

FIGURE 16
EFFECT OF PHASE UNBALANCE



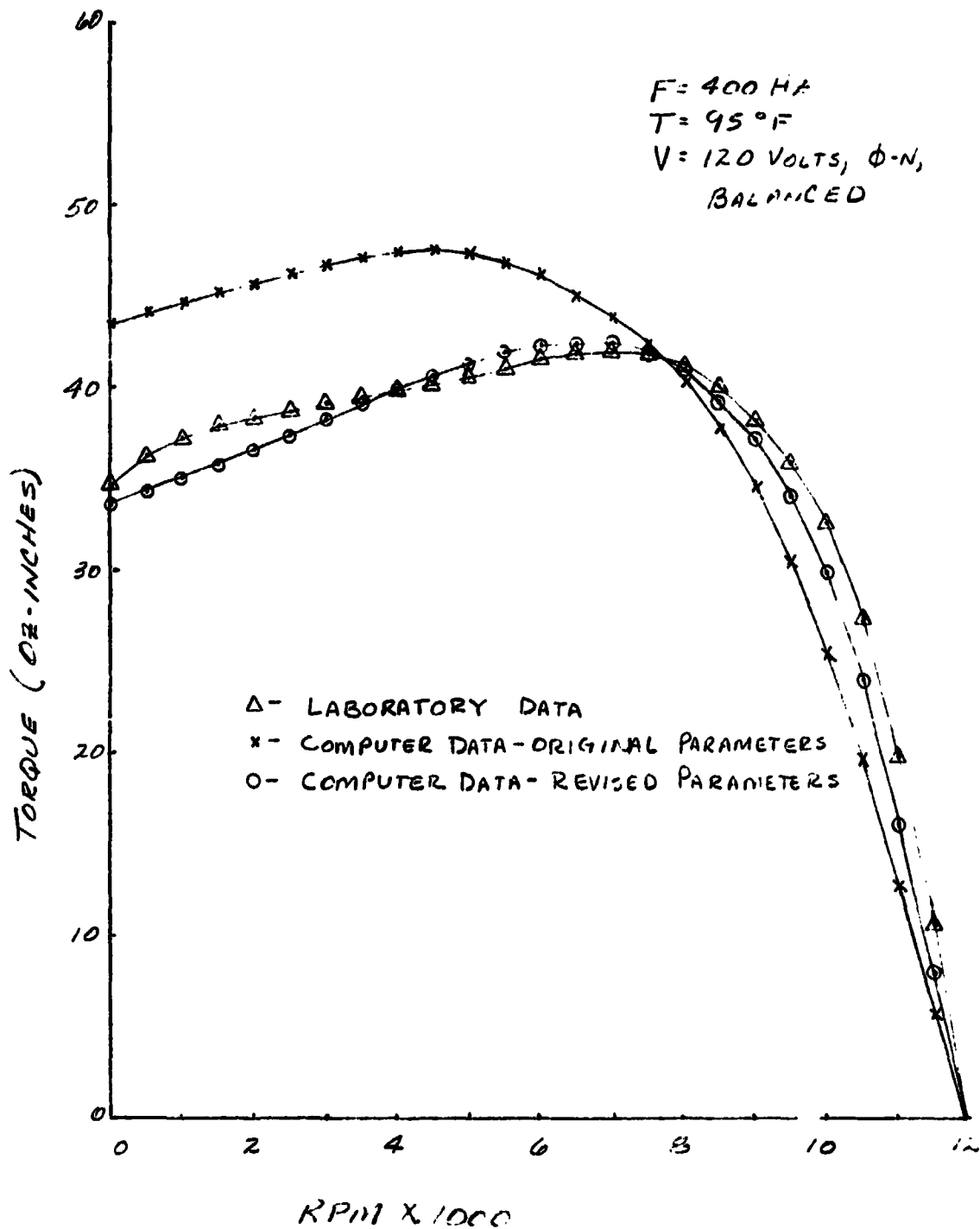
BY: <u>WIP</u>	DATE: <u>2/12/77</u>	SUBJECT: <u>SAWYER MOTOR</u>	SHEET NO. _____ OF _____
CHKD. BY: _____	DATE: <u>4/20/83</u>	<u>9-11, 30, 400 Hz</u>	JOB NO. _____
COMPUTER: <u>2.11</u>	<u>62</u>	<u>0.12 HP, 10,700 RPM</u>	_____

FIGURE 17
EFFECT OF TEMPERATURE VARIATION



BY 7228W DATE 1/6/77 SUBJECT SAWYER 11-FAIS SHEET NO. _____ OF _____
 CHKD. BY _____ DATE _____ P/N 42910309-11; 30; 400Hz JOB NO. _____
 _____ 0.12 HP; 10,700 RPM _____

FIGURE 18
COMPARISON BETWEEN LAB. AND COMPUTER DATA



BY WJW DATE 4-28-77 SUBJECT SAWYER MOTOR SHEET NO. _____ OF _____
 CHKD. BY _____ DATE _____ P/N 42010309-11.32; 400HZ; JOB NO. _____
 COMPUTER DATA # 2 0.12 HP; 10,200 RPM

FIGURE 17
STARTING AND BREAKDOWN TORQUE
VERSUS TEMPERATURE

